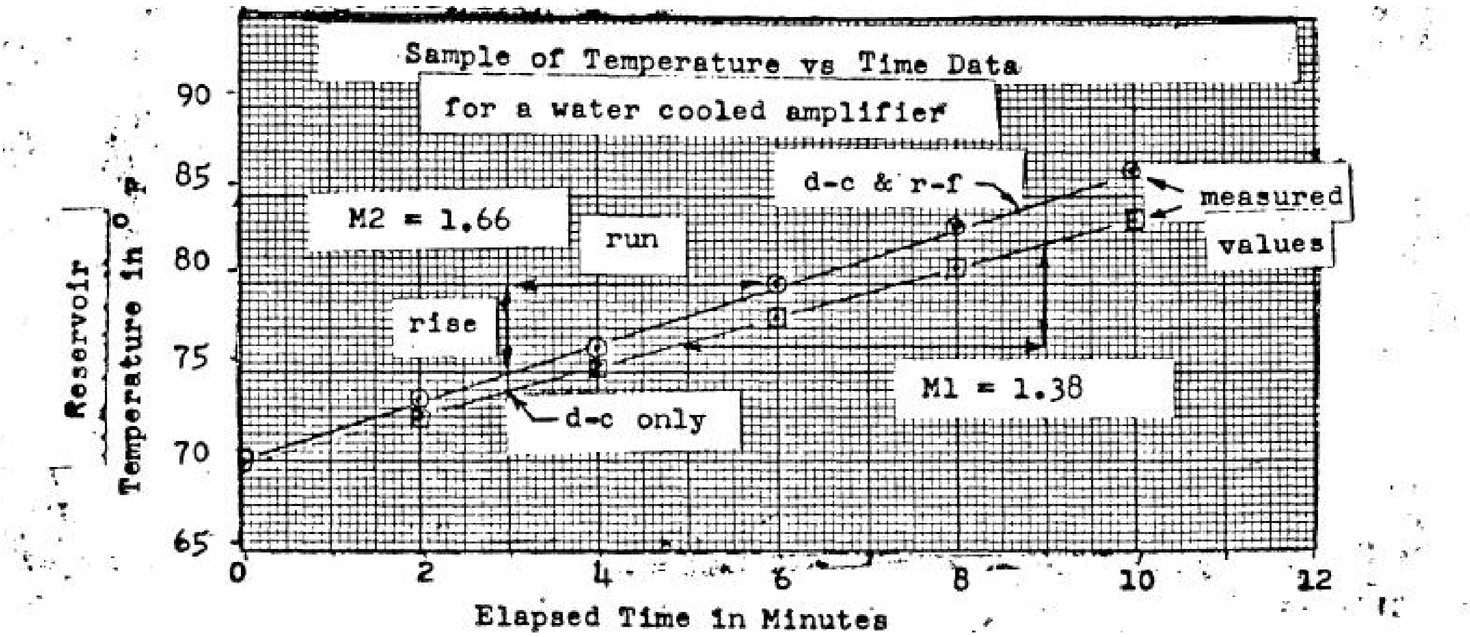
Technical Report # 7
From: The Crawford Hill VHF Club, W2NFA Date: December, 1971

Subject: POWER MEASUREMENT at 1296 mc/s

Direct power measurement at 1296 mc/s in the range above a few watts has always presented a problem for the experimenter unless he is fortunate enough to have one of the few direct reading calibrated high-power watt meters for the L-band frequencies. This report presents a very inexpensive but accurate method of determining output power of an amplifier at 1296 mc/s by a heat equivalence method. The accuracy is largely determined by the accuracy of the d-c meters used to measure the d-c input power to the amplifier. The disadvantage of this method is that it is not instantaneous but is an integration process requiring a finite amount of time during which the amplifier must be maintained at constant input and output levels. The method can be applied to both air and water cooled amplifiers with suitable procedures for each. This method is especially useful to those experimenters who must rely totally on their own resources for measurement of r-f power.

Water Cooled Amplifiers:
In a water cooled amplifier where the flow rate is sufficient so that the water temperature in the anode jackets is essentially the reservoir temperature, the anode dissipation appears as a rise in reservoir temperature. If the cooling system is at room temperature
to begin with and the anode dissipation is held at some constant value, for instance 500 watts d-c with no r-f drive, the temperature of the reservoir will rise in a very linear manner over a period determined mainly by the quantity of water in the reservoir. A 2 gallon reservoir will rise in temperature from 70°F (21°C) to 80 F (26.5°C) in about 6 minutes with about 500 watts of power dissipated into the cooling system. The slope of the line graph plotted from measured data, temp. v.s. time, is therefore a measure of the power going into the cooling system.

Samples of this data are shown plotted below.



If the power dissipated into the reservoir is continued for a longer period, eventually the rise in temperature will no longer be linear but will tend to saturate mainly due to radiation and conduction heat losses.
Thus far d-c calibration for a constant known dissipation was measured. It is a simple extension of this notion to realize that with an amplifier operated AØ on a single frequency, the difference between the d-c anode input power and the power dissipated into the water cooling system must be the r-f power output delivered by the amplifier.

The only additional piece of equipment required is an inexpensive thermometer in the reservoir. The thermometer need not be accurately calibrated as long as it can be read in the temperature range of interest with about 1 or 2 degree steps. The thermometer is used to establish the slope of the linear temperature vs time graph and it is immaterial to the method what temperature scale is used.

The precautions which need be followed in this method are:

(a) Maintain the system unchanged during a series of measurements,
(b) Maintain the volume of water constant in the system, and
(c) Always start a measurement at or near room temperature. This latter precaution may be very time consuming and it may be expedient to add a sufficient quantity of ice to the reservoir between measurements to force the reservoir temperature down to room temperature correcting the water volume as required.

In order to estimate how your particular system water temperature will rise it takes 146.8 watts of power to raise one gallon of water 1°F in one minute at standard Earth pressure, 14.7 pounds per square inch.

1 gallon = 3.785 liters

Temp.° Centigrade – 5/9 (Temp. °F 32°F)

Procedure

Suppose a water cooled power amplifier for 1296 mc/s has the capability of the maximum U.S.A. legal d-c plate input power of 1000 watts, and its efficiency is expected to be approximately 50%. The expected r-f output power should be 500 watts. To actually determine the output power, start with the system water temperature at approximately 70wF and operate the amplifier in a normal manner, tuned and loaded for maximum r-f output power with the d-c plate input power set and maintained at a constant 1000 watts.
Take a reservoir temperature reading at regular intervals say 1 minute apart and plot this data on rectangular graph paper as shown on page 1. Recording many points will allow a more accurate determination of the slope and also a check on the saturation temperature. The plot should be quite linear over at least the first 10 rise in temperature.
he slope of this linear plot of measured data is now determined in F/minute (rise divided by run) as shown by the graph on page 1.
The slope in this case is determined to be 1.66°F.Min.

Next, the reservoir temperature is returned to 70 F and the amplifier bias is altered so that <u>without</u> r-f drive, the amplifier will draw sufficient total anode current so that the d-c plate input power will be 500 watts. Repeat the temperature recordings at 1 minute intervals and plot this data on the same graph paper. A typical set of measured
-values are also shown by the graph on page 1. Again determine the slope of this second linear plot to be 1.38°F/minute in this case.

The r-f output power is then

$$P_{\text{r-f out}} = 1000 \text{ w.} \quad \frac{1.66}{1.38} \times 500 \text{ w.} = 400 \text{ w.}$$

As a further check on the measurement, another d-c only run can be made with the d-c input power set for 600 watts, for this example. The resulting plot should have exactly the same slope as in the case when the amplifier was delivering r-f output power.

Air Cooled Amplifiers

A similar output power determining technique may be used with air cooled amplifiers. In this case the thermometer is placed in the exhaust air stream and the exhaust temperature is allowed to stabilize (saturate) for each measurement. Precautions similar to the water cooled case are:

(a) Sufficient air flow be maintained so that the tubes do no overheat in normal operation,

(b) Arrange the plenum so that all tubes (if multi tube amplifier) receive approximately equal air flow. And more important that all exhaust air streams are collected into one exhaust port where the thermometer is located.

(c) Locate the exhaust thermometer about six inches or so away from the amplifier proper so that direct radiation from hot metal parts does not effect the exhaust temperature readings.

Procedure:

The procedure in the air cooled amplifier case is to first operate the amplifier in its normal mode delivering r-f power to the antenna or dummy load for a sufficient time to permit the exhaust temperature to stabilize. Typically, a few minutes depending on the air flow rate will be long enough. Record this temperature carefully and record the total d-c plate input power, $I_{dc} X E_{dc}$ total measured directly in the anode circuit. The absolute temperature is unimportant.

Next with NO r-f drive to the amplifier, adjust the bias so that the amplifier draws anode current and is stable (no oscillations). Keep the load on the anode output circuit to prevent possible oscillations. The amount of current drawn by the amplifier anodes should at first be set according to the expected approximate efficiency. That is, if the expected efficiency is 50% then set the bias so that the anodes receive about half the d-c current that was measured with d-c plus r-f operating conditions. Now note the exhaust temperature when stabilized. If it is higher than the recorded temperature measured under d-c plus r-f conditions, lower the d-c anode current (input power d-c) by adjusting the bias and vice versa. The object is to match the temperature reading obtained under the d-c plus r-f conditions with d-c alone (heat equivalence). When this has been done, record the total d-c input power.

The r-f power output of the amplifier is then the difference between the anode d-c power under normal operating conditions and the d-c anode power under no r-f drive conditions. The simplicity and

directness of power determination by this method should now be evident and also that the thermometer calibration plays no part in the accuracy of the results only acting as a reference of exhaust heat equivalence.

Remarks

A special comment should be made regarding determination of anode current and voltage for computing total d-c input power. In a grounded grid amplifier with cathode bias, the anode voltage is NOT the supply voltage nor is the cathode current the anode current. The anode voltage is the supply voltage minus the measured cathode voltage at a given cathode current. Likewise the anode current is the cathode current minus the grid current in the r-f drive case. It is advisable therefore to measure anode current and voltage directly at the tube terminals with separate meters and with proper precautions for safety. The anode voltage is measured with a voltmeter connected directly from anode-to - cathode and the anode current should be measured with the meter directly in the anode supply line. Only from these direct readings should total anode input d-c power be computed.

One further comment should be made regarding absolute accuracy. Some of the r-f power generated in the anode circuit of the amplifier may be dissipated in the anode circuit, cavity walls, joints, etc., and will not appear as heat at the anodes of the tubes. This will result in slightly optimistic determination of useful output power. Note that the true output power is determined by this method but it can not all be recovered at the output port. In general; the amplifier with poor efficiency will produce the greater error of this type.

As an example of the magnitude of this type error, data taken on an amplifier at 1296 mc/s with poor total efficiency indicated an output power of 29 watts for 100 watts d-c input power while the true output power measured directly at the output port was 25 watts. The 14% (0.7 db) error can in part be accounted for by the d-c meter inaccuracies but is believed to be largely due to circuit losses in the anode cavity. The saturated exhaust temperature for this particular case was 124°F.

If other devices are used to measure temperature, such as a thermistor, it is advisable to determine the effects of stray r-f fields on the operation of such devices. Indeed, a mercury column thermometer may be affected if its column length is near half wave resonance at 1296 mc/s. It may be advisable to use alcohol thermometers in cases where stray r-f leakage is occurring.

The accuracy of your d-c meters to measure both anode current and voltage should be ascertained if absolute output power determination is desired. It is interesting to note however, that even with inaccurate meters, the plate efficiency may be determined with high accuracy.

While power determination at 1296 mc/s has been stressed in this report, it should be obvious that the heat equivalence method can be applied at any frequency.

Contributions by W2CQH and WA2VTR are acknowledged.